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PLATE 19

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I. Introduction.

At its northern end the Caledonian granite massif of Leinster displays well-marked post-consolidation effects in the form of marginal zones of shearing along either flank. The relations of these features to the general structural history of this part of the mass are discussed in a recent communication (1954), and it is shown that they represent a final episode in the emplacement process, at a time when the igneous body was essentially in a solid condition. Sollas (1889, 1891), in his classical studies of the granite, has described the microscopic features of the deformed types and demonstrated their cataclastic origin. The present study, which confirms in essentials his findings, is directed towards an examination of the mechanical behaviour and deformation mechanism of the solid granite on the northern and western margins of the massif. It will be understood, therefore, that this study deals simply with a type of mechanical alteration which reached considerable intensity in the final phase of the igneous history; it does not necessarily reflect the magnitude of its effects in relation to the emplacement of the granite body.

II. General Geological Relations along the Northern and Western Margins of the Massif.

The granite of the area belongs to the Type II variety (Brindley, *op. cit.*)—a medium-grained, variably porphyritic, microcline-granite with steeply inclined flow schlieren and biotite parallelism arranged conformably to the walls of the intrusion (Fig. 1). The Lower Palaeozoic country rocks adjacent to the mass are contact-metamorphic muscovite-schists in which the prevalent schistosity structures likewise lie parallel to the direct north-north-easterly trend of the plutonic boundary. Along

its western flank the cataclastic effects, superimposed with similar orientation on the primary flow structures, increase in intensity towards the granite-schist junction, where a mechanically-foliated gneissose granite (Sollas, 1891, p. 496) is developed ; white mylonites—of aplitic aspect—here appear in vertically disposed zones reaching a few feet in thickness as the ultimate stage in mechanical breakdown. Discontinuous sheets and lenses of pegmatite and aplite, and quartz-tourmaline veins, are locally intercalated along the foliation direction of the crushed granite, and have themselves been involved in the deformation ; similarly-affected cross-cutting dykes also show distorted forms. Actual contact exposures, which occur at three localities (Mount Venus, Piperstown, and the Glassavullaun brook on the south side of Glenasmole), show this junction as a smooth movement plane which coincides with the general structural trend. It is apparent, therefore, that after consolidation of the igneous mass its marginal portion operated as a zone of weakness along which strong deformation has taken place.

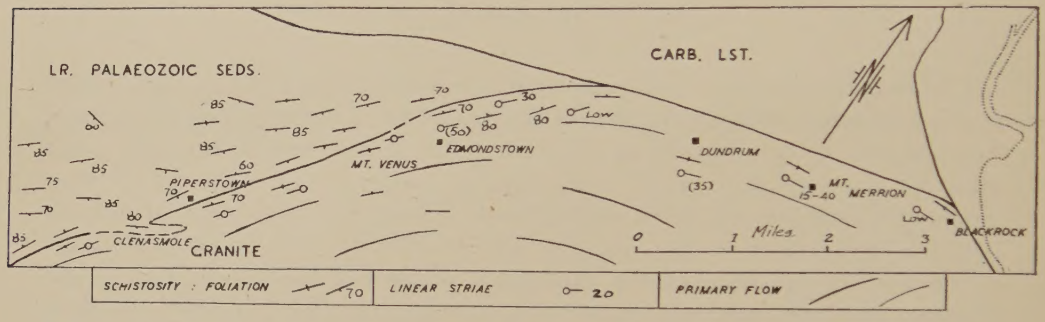

FIG. 1. Arrangement of structural features in the northern and western flank areas of the Leinster Granite mass.

Though severe cataclasis is commonly restricted to within a few hundred feet of the contact—and would appear to be unequally developed at different places along this flank—the more general effects occur through a broad marginal zone of the igneous rock. At some localities (e.g., Edmondstown) notable, if weak, deformation is still evident at a distance of half a mile from the boundary, and is seen through exposed thicknesses of several hundred feet at the outcrop. With lessening intensity it passes inwards to local zones of incipient crushing, sometimes present more than a mile from the granite margin (Rockbrook), and marked by a pronounced parting direction parallel to the primary flow structures. While the marginal granite is most severely affected in this way, all three varieties, including the central Type III rock (e.g., at Kilmashogue) display these weaker effects, and it is likely, therefore, that the border-zone deformation succeeded consolidation of the entire igneous body, at least down to its present level of exposure.

At the northern end of the plutonic mass its margin is concealed beneath unconformably overlying Carboniferous Limestone rocks ; the flow form, however, indicates that the termination of the body here lies not far north of the present limit of granite

outcrops (Fig. 1). Granite outcrops close to the limestone boundary continue the sheared border zone of the western flank around this end, by Mount Merrion to the sea-coast at Blackrock. Weakly developed mechanical effects of the usual character are generally present along this belt, arranged in relation to the primary flow form, and at the latter point an unusual local feature—in the nature of a coarse granite-breccia—is developed in association with the slightly deformed granite. It is situated at the Carboniferous Limestone/granite boundary, and has recently been described by Turner (1950, p. 172) as of sedimentary origin.

III. Macroscopic Structural Features of the Marginal Granite.

The chief structural features may be listed as follows :—

1. Primary flow features—flow banding, mineral parallelism.
2. Primary fracture features—pegmatite-aplite dyke systems.
3. Later mechanical features—quartz vein sets (scarcely represented in this area), parting and jointing systems, textural cataclasis and foliation effects.

The present communication is concerned with the latter group of features. These post-consolidation structures include both ruptural effects—jointing and parting systems—in the mass of the rock, and solid deformation features affecting its texture ; the latter comprise foliar and linear elements, together with microfolds developed in the foliated material. The accompanying block-diagram (Fig. 2A), which is constructed from field measurements of the minor structures in the Mount Venus quarry, illustrates clearly their mutual relations.*

(i). Series of *partings* are generally present as directions of weakness in the massive rock developed in quarrying or as natural outcrop surfaces, or brought out by weathering as minute sub-parallel cracks and fissures ; in local zones the latter may be closely spaced, so that the rock breaks down in a flaky manner. Three regularly orientated sets of partings are found in this area. The most prominent, or " rift," direction is steeply inclined, and generally parallel to primary flow features of the massive granite. It is seen to give way to a cataclastic foliation in the highly deformed rock, along which the material flakes readily. A second parting direction, or " grain,"—perpendicular to the rift and with a near-horizontal orientation—is also commonly present ; it is macroscopically well-marked, even in the mylonitic

* In view of the complex nature of the deformation the conventional notation is here omitted —in the interest of simplicity—in describing these features.

granite (Fig. 2A), where it is seen to post-date the main deformation effects. Evidence of a third, or " hardway," direction, at right angles to the other two has been observed in micro-section as a weaker development (*vide infra* p. 331). These features are not accompanied by any evidence of intergranular movements in the rock, and earlier cross-cutting veins and dykes remain quite undistorted.

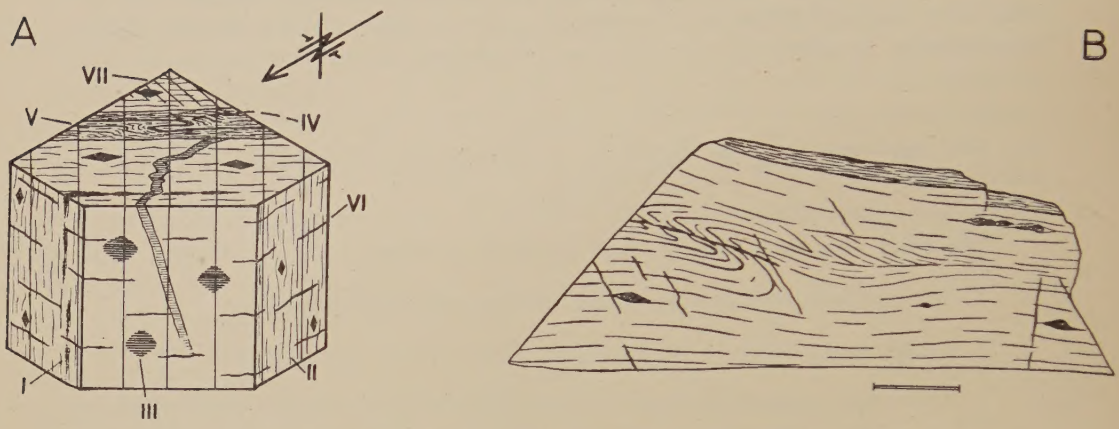

FIG. 2. A. Block-diagram constructed from measurements taken in the Mount Venus Quarry to show the relations of the various minor structures in the granite. Vertical biotite schlieren (I) with north-easterly trend are associated with a corresponding mechanical foliation of the rock (II) in which large felspar porphyroclasts show a horizontal arrangement of their major axes. On the foliation surfaces linear striae (III) lie horizontally, and in thinly laminated mylonite zones discontinuous slipping effects have sometimes resulted in buckling of the foliae (IV); distorted aplite dykes are also shown. Fracture elements belonging to this mechanical system are a dominant group of vertical cross-joints (V) and a flat-lying parting direction (VI) also at right angles to the foliation. A subsidiary, east-west series of cross-joints (VII) is associated with a local, north-south, crush zone.

B. Camera lucida drawing of a specimen of mylonite from the contact region, Mount Venus Quarry. General closely spaced foliation banding and scattered felspar augen, together with a prominent recumbent micro-fold with displaced middle limb. *In situ* this face would lie in a horizontal position and it corresponds to the parting direction in Fig. 2 A. At the upper part of the specimen another face is partly visible and shows a foliation surface with linear striae which are arranged at right angles to the folding. Subsequently formed oblique-lying systems of fissures intersect the foliation symmetrically parallel to the fold axes at an angle of approximately 54°. A few cross fissures are also visible. The line below the figure represents 2 cm. approx.

(ii). *Joint sets* are distinctly recognisable at most localities, though in the massive rock there is much irregularity in their arrangement. Nevertheless, over the whole area the fracture pattern is found to vary persistently in accordance with changes in the general structural trend, as defined by foliation and other elements, thus indicating their mutual association as a single mechanical system in relation to the deformative stresses. In the sheared types along the western flank, however, a rather rigidly arranged jointing system is widely in evidence (Fig. 3). Here a well-marked set of steeply-inclined cross-joints lies perpendicular to the foliation, as smooth,

undistorted, and rectilinear planes which are observed to pass directly through the various mineral grains of the rock without regard to orientation or crystal structure. In the massive granite this is also the most prominent joint set at any particular locality and lies perpendicular to primary flow structures ; it also coincides with the main quartz vein set of the massif (Brindley, *op. cit.*). Another joint set is commonly present parallel to the primary flow trend, though in the crushed rock its members tend to merge with the general foliation and are replaced by the platy structure or fissility which accompanies it. This set shows a steep or vertical orientation at right angles to the main cross-joints, and thus corresponds in position to the rift direction of the granite. At some places a third set of joints, perpendicular to the other two, is also present : it is most commonly represented by a prominent parting (the grain) but may, however, appear locally as a well-marked set of smooth, spaced joint planes (Fig. 3B).

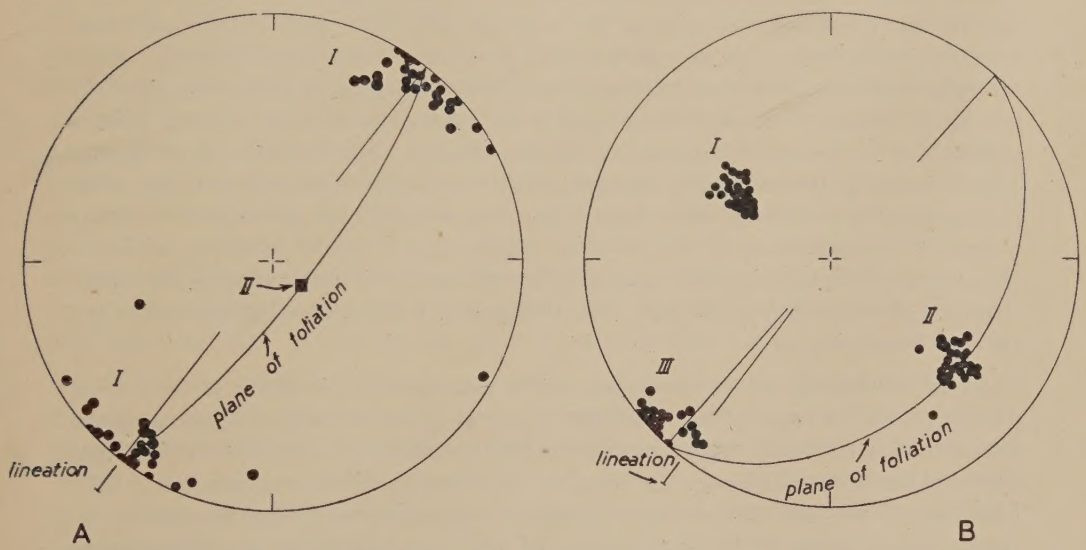

FIG. 3. Minor structures of the granite. Poles of joints and partings plotted in upper hemisphere of Schmidt equal-area net.

A. Crushed granite and mylonite in contact zone. Streamlet on north side of Piperstown Hill. All observed joints are plotted. A single set of vertical cross-joints (I) is arranged perpendicular to the foliation and to the horizontal linear direction. Near-horizontal partings (II) at right angles to foliation and cross-joints are visible in the form of natural surfaces in the outcrop.

B. Crushed granite with pegmatite lenses intercalated along the foliation direction ; Owendoher stream near Edmondstown. A minor number of joints belonging to unrelated, oblique-lying sets are here omitted. Foliation inclines at medium angles to the north-west ; linear striae show a north-easterly pitch at medium or low angles. The chief fracture elements comprise series of parting planes corresponding to, and tending to merge with, the foliation (I), a well-defined set of perpendicularly arranged joints (II), and the usual steep cross-joints (III)—all at right angles to each other.

Systems of oblique-lying shear joints, whose members are symmetrically placed in relation to the foliation of the rock, are of rare occurrence and have only a very minor significance. A local example appears in Fig. 2B.

(iii). Series of *steeply-inclined foliation surfaces* which are seen microscopically to be a result of intergranular deformation, with development of secondary muscovite along the surfaces, are generally present in the sheared granite. In the less seriously deformed types they appear as undulating planes discontinuously spread through the rock, and, where more extensively developed in the gneissose varieties, are seen to envelop large felspar crystals and flaser-like lenticular areas of the ground-mass with development of a typical augen structure. In the mylonites they are continuous and closely spaced laminae, lying in beautiful fluidal forms around conspicuous porphyroclasts of various sizes, and interspersed with lenticular sheets and foliae of less highly comminuted materials.

(iv). *Linear striae* with a uniform near-horizontal pitch, which are identical in appearance with ordinary fault slickensides, are generally observable on these foliae throughout the marginal zone of the pluton. They appear in the form of a fine scoring on the smooth surfaces, or on a coarser scale as rough parallel grooving. Smearing-out of the secondary mica in this direction is sometimes observed, and in strongly crushed zones felspar augen tend to lie with their longest dimensions similarly arranged. Direct evidence of the nature of the movement in these foliation zones is available in the Mount Venus quarry (Fig. 2A), where steep-lying dykes are mechanically distorted in traversing the gneissose rock resulting in vertically-pitching undulations which are, in effect, weak shear folds. It is seen that the deformation involves a general foreshortening in the direction perpendicular to the foliation, with displacement of material laterally indicated by the resulting contortion of the dyke; steeply inclined rock faces do not show evidence of a corresponding distension in a vertical direction.

(v). *Small-scale fold structures*, repeatedly developed in the foliae of the mylonite, are present in specimens from Mount Venus (Fig. 2B) as tight recumbent microfolds smoothly enclosed within the adjacent layers; they lie strictly orientated at right angles to the linear structures and thus have a general vertical arrangement of their fold axes. These features evidently result from interlaminar gliding movements on the micaceous layers, which have produced a local buckling of the intervening foliae, and they thus serve to demonstrate that the widely developed border zone lineation is in the nature of an internal slickenside effect involving movement in the direction of the striae (a lineation in *a*). It is evident, therefore, that cataclastic deformation of the granite was accomplished essentially in a horizontal direction, at right angles to the regional compressive stresses.

IV. Micro-structures and Textures of the Marginal Granite.

The normal marginal granite variety (Type II) is a medium-grained microcline-oligoclase-quartz rock, commonly with biotite in excess of muscovite. The potash-felspar is present in large fresh irregularly-bounded crystals, which enclose plagioclase and biotite; they lie in finer-grained surroundings of hypidiomorphic plagioclase, with

dark and white micas—chiefly in clusters of a few individuals—aligned to the primary flow direction. Quartz areas, each made up of a number of interlocking grains, are largely interstitial to the other constituents. Widely developed late-stage changes include the formation of secondary muscovite in the felspars, myrmekitic growths, and secondary quartz with embaying outlines towards the other constituents.

The granite from the coastal outcrops just east of Blackrock railway station is typical of the normal marginal variety and shows incipient deformation effects. It is massive, strongly-jointed, and with prominent parting zones marked by series of tiny fissures which lie approximately parallel to the vertical flow trend. Micro-sections reveal a texture primary in character and with the constituents essentially intact. The quartz grains of the interstitial mosaic, however, generally show uneven extinction, and in some of the larger individuals pronounced strain effects are evident. In these it is observed under crossed nicols that the areas of varying interference tint within a strained crystal tend to be distinctly separated off from one another by distinct, though faint, boundaries. A further stage in this development shows these large primary quartz grains, or superindividuals, each made up of a number of clearly defined small units which diverge slightly in orientation, though the original shape of the large grain is still evident. This marks the beginning of a new quartz mosaic, and with its further development the forms of the primary quartz grains are entirely obliterated by the reconstitution process ; general cataclastic effects appear throughout the rock at this stage. Quartz deformation in the granite is thus connected with intra-crystalline lattice strain effects of a strictly mechanical nature ; it is generally similar to the behaviour of this mineral studied by Sander (in Knopf and Ingerson, 1938, p. 170) by the more rigorous methods of petrofabrics.

Rectilinear or slightly undulating planes, lined by swarms of tiny bubble-like inclusions, mark incipient fissures in the quartz, but do not appear to be closely associated in development with the strain polarisation effects or with the formation of the new quartz mosaic. They are present ubiquitously in the coarse mosaic areas, in some cases traversing several grains without deviation while elsewhere terminating at the inter-grain boundaries, and are also occasionally observed to extend into felspar crystals. These features are seen to lie in clearly marked, if somewhat irregular, sets, which occur generally throughout the rock and coincide with its macroscopic partings. They are thus evidently independent of the crystallographic orientation of the quartzes and are considered to be related simply to the principal stress directions. The illustrations (Fig. 4A and B) show three mutually perpendicular sets of these fissures, (i) parallel to the rift direction and primary biotite parallelism, (ii) in the direction of the grain, or near-horizontal parting, and (iii) forming a less perfect, hardway, direction in line with main cross-joint set. Correspondingly, uneven small scale cracks, which traverse a number of mineral grains without causing displacement, and at times follow the grain boundaries, lie parallel to the rift direction ; they are in places associated with the more finely developed planes of inclusions, and represent the series of small macroscpoic fissures visible in the granite outcrop.

The large microclines of the rock have strongly emphasised cleavages in the form of series of plane fissures or as uneven cracks along this direction ; the effect is here evidently controlled by crystal structure rather than general stress direction, for the fissures are seen to lie at various angles to the main parting lines. Plagioclase is generally unaffected by strain, but the micas may show a slight bending of the cleavage laminae noticeable by wavy extinction effects.

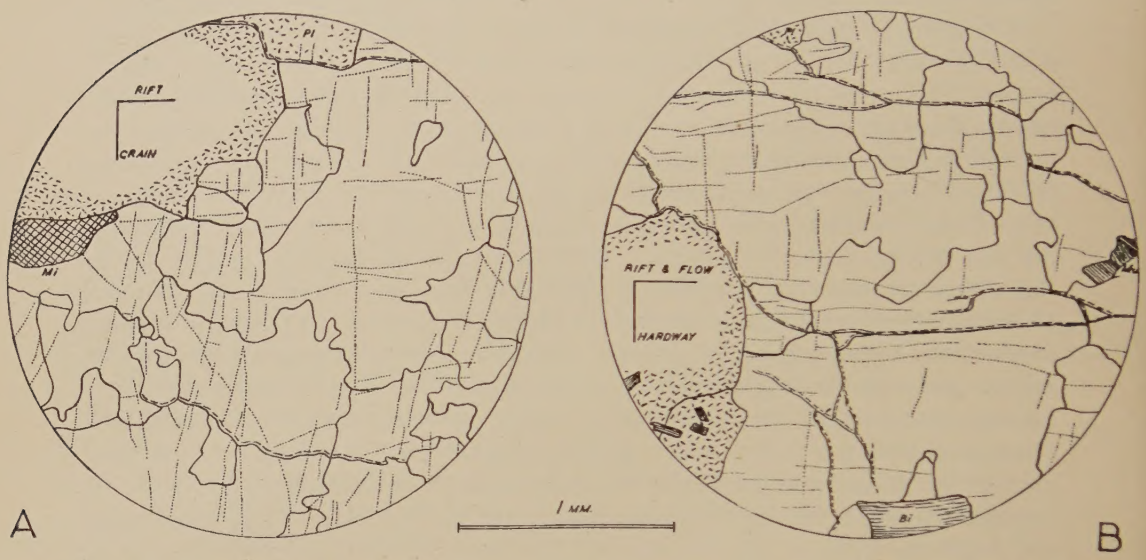

FIG. 4. Microsections of the Blackrock Granite. Specimens collected at the sea-coast a short distance west of Blackrock railway station.

A. Section vertically-inclined and at right angles to the primary biotite parallelism. Planes of inclusions in the quartz, parallel to the grain (predominant) and rift directions, are clearly defined and mutually perpendicular.

B. Section horizontally orientated and perpendicular to the primary biotite parallelism. Planes of inclusions correspond to the rift (predominant) and hardway directions. Irregular cracks (indicated by double line), chiefly following the grain boundaries, run generally with the rift direction—these represent the macroscopic series of partings or tiny fissures visible in the outcrop.

It is seen, therefore, that in the essentially non-cataclastic granite—as exemplified by the Blackrock material—three mutually-perpendicular series of planes of inclusions developed in the quartz correspond to the parting directions of the rock. This is broadly speaking in agreement with the results obtained in other granite masses, though the Leinster rocks apparently show a more complete development than is usual. Thus Cameron (1945) has found in the Aberdeen Granite that the inclusion planes form a single well-marked series in line with the hardway direction of the rock and also with the main cross-joint set ; the better-developed rift and grain directions are, however, unaccompanied by recognisable microscopic features. Dale (1923, p. 17-22) has carefully examined similar effects in some New England granites, and finds two series of perpendicularly-arranged micro-fissures correspond-

ing to rift and grain directions ; his descriptions agree in detail with the Leinster Granite partings. Unfortunately this author makes no mention of any micro-characteristics of the hardway direction.

The Mount Merrion exposures of slightly crushed granite feature a rather more advanced stage of mechanical breakdown. Here the rock retains generally the steeply inclined flow texture, though evidence of slight cataclastic effects in this direction is seen macroscopically in weakly defined discontinuous movement surfaces carrying faint striae. Occasional biotite film schlieren have acted as weak structures, and are noticeably striated, but sharply rectilinear dykes traversing the rock demonstrate that the pervasive deformation effects are insignificant.

Microscopically, the rock shows initial stages of cataclasis, without extensive mechanical disorientation of its primary igneous fabric (Pl. 19A). Most noticeable is a general breakdown of the quartz areas resulting in textural features very different from those of the normal granite. Remaining large grains of this mineral show the usual strain polarisation and planes of inclusions, but for the most part the individuals have been reconstituted to a host of minor grains. They often display highly elaborate boundaries and a general dimensional elongation in zones winding among the large felspar and mica crystals ; there is no noticeable disturbance of the arrangement of these latter constituents. The planes of inclusions and wavy extinction effects are not conspicuous in this reconstituted mosaic, but a notable feature is the development of tiny plates of white mica of secondary origin, which appear locally associated in undulose films aligned to its general crush direction. The original mica and potash-felspar crystals in some cases show bending and fissuring effects, respectively, and in addition the plagioclase is frequently marked by uneven extinction and fracturing, with slight dislocations, along its cleavage.

In the Mount Merrion granite, then, mechanically-controlled reconstitution of the quartz areas, together with the appearance of secondary muscovite films, is responsible for the development of a foliation in the rock, visible macroscopically as series of *s*-surfaces parallel to its flow trend. These textural changes have resulted in slight fracturing and distortion of the other constituents, due evidently to integral strain adjustments within the quartz fabric, and without causing, at this stage, general disarrangement of the primary granite texture ; they have not resulted in significant deformation of the material *en masse*.

In the gneissose marginal granite at Edmondstown, Mount Venus, and other localities along the west flank, mechanically produced foliation conformable to the walls of the intrusion is the dominant structural feature of the rock, and its deformation *en masse* is sometimes demonstrated by the distorted forms of cross-cutting aplite dykes. Extensive cataclasis is visible under the microscope as a development of the features already described, and has effectively obliterated primary textures (Pl. 19B). The quartz areas are completely reduced to an exceedingly fine-grained and elaborately interlocked mosaic, in which elongation along the foliation direction may sometimes give rise to extremely attenuate forms ; these trituration zones are

associated with films of secondary muscovite, and wind smoothly around relics of the primary material as a more or less continuous ground-mass of the rock. The primary relics thus appear as lenticular " islands," each composed of a few mineral grains and showing various stages of cataclastic breakdown ; indications of peripheral granulation are present, and some of these isolated units also show evidence of bodily rotation. Felspars and micas display severe bending and strain effects, and are often cut up by internal displacements along the cleavage direction ; in places disintegrated felspar crystals remain as clusters of fragments representing a single large individual from the original rock. The crush zones of quartz and white mica are strewn with small felspar fragments from more complete trituration effects.

Close to the granite contacts along the west flank zones of compact even-grained mylonite represent the ultimate stages of mechanical breakdown of the plutonic rock, and in some cases have similarly developed from aplite-pegmatite sheets intercalated along its crush direction. These types are thinly laminated and fissile in character, due to the presence of continuous films of extremely fine-grained yellowish sericitic mica, which separate slender lenticular foliae made up of triturated constituents of the original rock, commonly no more than a fraction of a millimetre in thickness. Large beautifully rounded ovoids of potash-felspar—chiefly microcline—up to two centimetres in length are scattered through the rock, smoothly enveloped by the banding, and occasional tiny pink garnets are present.

Under the microscope the rock texture is seen to be composed of the usual quartz trituration zones, interspersed with films of sericitic mica and lying in parallel or smoothly undulating fashion so as to extend through the whole area of the section (Pl. 19c) ; remnants of the original granite fabric are no longer generally seen. In many examples fragments of the primary constituents—chiefly felspar—with angular shapes and of various sizes, lie dispersed in this ground-mass, giving rise to typical mortar-structure in an advanced stage of development. In the finest mylonites, however, the texture is even-grained and only slightly irregular ; individual microfoliae show coarser features internally, and grade out to a finer texture as the mica films bounding the layer on each side are approached. Biotite is no longer noticeable in the ground-mass, though large plates of muscovite, variably distorted, are of frequent occurrence. The large potash-felspar crystals—sometimes quite intact and but slightly reduced from their original dimensions—are seen occasionally as prominent augen-like porphyroclasts among the mechanically-formed foliae ; their primary nature as original constituents of the granite is indicated by the conspicuous presence of enclosed plagioclase and biotite as undeformed hypidiomorphic crystals in the manner characteristic of the normal Type II variety. " Tails " of coarse quartz-felspar aggregate with associated plates of chloritised biotite—also representing relics of the original granite—are present in the protected areas on either side of such large crystals.

Crystallisation features are generally evident in the triturated quartz mosaic, which shows the usual complicated boundaries ; in detail, similar sutured junctions

occur between this constituent and felspar, though on a broader scale the latter forms show typical fragmental outlines. The secondary muscovite, so profusely associated with quartz in the trituration zones, commonly appears as a plexus of tiny undeformed scales with a general orientation in the foliation direction, though bending and crush alignment effects are locally in evidence. The scattered grains of garnet—likewise undeformed—are newly-developed constituents in the rock, apparently as an effect related to the aplite-pegmatite phase of the igneous history of the massif.

Mylonitic derivatives of the aplites are of analogous character and of closely similar composition. They are composed of microcline, plagioclase, muscovite, quartz, and accessory garnet, and show corresponding dynamic metamorphic effects. Here, however, the plagioclase is a soda-rich, albitic variety, and no traces of biotite are found. These types grade into less strongly-deformed portions which retain undoubted aplite characteristics.

In the cataclastically deformed types the pronounced rift direction of parting corresponds to the foliation and in the gneissose granite and granite-mylonite results in a marked fissility ; the other two partings are also locally evident. The microscopic planes of inclusions are no longer noticeable in the quartz and examination of thin sections has not revealed the presence of other intragranular structures which might be related to these features. It seems most likely that rupture connected with the partings is here initiated along intergrain boundaries in the fine-grained foliated texture of the rock.

V. Summary and Discussion.

Post-consolidation deformation effects along the northern and western margins of the Leinster Granite constitute a sheared border zone to this part of the massif, corresponding in arrangement to its primary flow form. They increase in intensity, with development of gneissose granite and ultimately of mylonitic types, towards the plutonic border, where clean-cut mechanical contacts are present on the western flank ; a continuation of this marginal zone around the northern end of the mass is indicated by similarly arranged, though weaker, crush effects.

The cataclastic breakdown of the granite is seen to result from differential mechanical behaviour of its various constituents, with failure of the interstitial quartz—the most sensitive mineral under prevailing stress conditions—as a controlling factor. This has been accomplished with regard to the quartz fabric in a continuous manner, resulting in development of a new fine-grained mosaic of this mineral along undulating foliation zones. Correspondingly, stress adjustments in the felspars and micas, which lie scattered in this ground-mass, have taken place by bending and fracture, and lead, as pervasive deformation of the material progresses, to their gradual disintegration. A profuse development of secondary muscovite in these foliation zones has evidently resulted in enhanced differential movement

effects and the production locally of small-scale fold structures by interlaminar gliding. Widely developed augen structure is seen to be due to solid flow of the foliation bands around more rigid felspar porphyroclasts and around occasional scarcely deformed units of the original rock fabric.

Such differential cataclastic effects in dynamic metamorphism have been noted by other workers. Thus Sollas (1891, p. 501) in his Leinster Granite studies has drawn attention to the relative ease of deformation of the quartz in contrast to the behaviour of the felspar in the rock ; the authors of the North-West Highlands Memoir (1907, p. 597) refer again to the contrasted behaviour of these two constituents in gneisses affected by the dislocation metamorphism of the Moine Thrust.

The appearance of secondary mica, and also of smaller amounts of garnet, together with the association of pegmatite-aplite types with the mylonites, is considered to indicate that deformation in the border zone ranged throughout the entire post-consolidation period in the plutonic history.

Jointing and parting systems in the igneous rock correspond mutually in orientation. They exhibit features which suggest that, in the sheared border zone, they succeeded the main cataclasis. Both structures are present in undistorted fashion traversing the sheared granite, and it is seen that the pervasive deformation took place essentially by a continuous mechanism rather than as a development of such ruptural effects. They cannot, therefore, be considered simply as an incipient phase of the main cataclasis, but rather represent effects of a subsequent stage of deformation, and their interpretation as strain effects produced under lower confining pressures would appear plausible. They represent fracture of the material *en masse*, controlled by the prevailing stress directions rather than by the characteristics of its constituent minerals.

Three perpendicularly-arranged fracture directions are involved in the systems of jointing and parting developed in the area. They conform to the general structural arrangement in the igneous rock, and are thus considered to reflect the operation of weaker stresses acting similarly to those which produced the main cataclasis. In addition, a very local development of diagonally-placed shear-joint systems has been noted occasionally. These latter features are found to intersect symmetrically and at an acute angle in the direction (presumed) of the principal compressive stress ; they would thus correspond to the planes of maximum shear in the material (Bucher, 1921) and are interpreted as shear joints.

The members of the main rectangular joint system are evidently arranged as directions of pure tension and compression (Fig. 2A), with the main set of steep cross-joints as tension openings which sometimes carry vein fillings ; a second, less-important, flat-lying set of cross fissures is most commonly represented only by a parting direction, and a third set of joints is orientated perpendicular to the direction of maximum compression. Our knowledge of the arrangement of these structural elements has advanced but little since the work of Haughton (1858) nearly a century

ago, who indicated that in a mechanical system the major joint sets may develop in the planes which contain the principal axes of stress, and they thus represent the directions of pure tension and compression in the material. More recent experimental work (Balk. 1937, p. 32) has produced corresponding series of fractures in test materials, and Bridgeman (1938) has given a theoretical explanation of the mechanism of their formation.

Analysis of the system of minor structures and their behaviour indicates that deformation in the sheared border zone of the granite mass involved a foreshortening perpendicular to the plutonic boundary, with concomitant distension laterally parallel to its trend. It would appear, therefore, that the principal compressive stress at this stage operated perpendicular to the walls of the igneous body. The granite foliation would thus lie at right angles to it, with linear striae and the anomalous, vertically arranged, micro-folds evidently a result of secondary stresses in the deformation ; these latter structures are simple flexural folds in relation to differential slipping movements on the foliation surfaces. It is seen, therefore, that—subsidiary to the principal stresses—the effects of the resulting deformation have given rise to series of secondary features differing in orientation from the main structural arrangement, though fundamentally related to it in origin.

The development of such secondary structural features in a deformation—though they may, perhaps, be not unusual effects—has only recently received consideration in structural analyses. Thus Turner (1948, p. 180) indicates the possibility of development of minor folds and other structures in this way, while E. Cloos (1946, Pl. 3) has earlier illustrated a linear elongation in flowing glass at right angles to the principal direction of movement. The latter author (*op. cit.* p. 26) has also adapted such an interpretation to the microfold structures in the *a*-direction developed in the Moines along the North-West Highlands fault zone.

Sheared border zones are a notable feature of many granite plutons, and it has, in general, been held that the movements involved took place in a vertical direction. They are, in fact, considered to represent a continuation of the upward intrusive stresses in the solidified margin of the pluton under the influence of its still mobile core (Balk. 1948, pp. 114 and 123). Such effects do not appear, however, to have operated in the present instance. Although the structural elements of the late—cataclastic—phase of the Leinster Granite conform in arrangement to its flow form, and evidently immediately followed consolidation of the rock, the deformation in its border zone has tended to cause an extension laterally rather than in a vertical direction. The main quartz vein set of the massif represents a mechanical adjustment to this lateral extension (Brindley, *op. cit.*), and evidence has been stated to suggest that the feature developed in relation to external stresses, which influenced the behaviour of the igneous body after its solidification, rather than to the actual intrusive movements. It is considered, therefore, that the sheared border zone is most probably related mechanically to such stresses operating on the solid granite body.

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Explanation of Plate 19.

Cataclastic features of the granite. All photographs under crossed nicols. x 12.

A.—Slightly Crushed Granite. Mount Merrion Hill.

Reconstituted quartz mosaic, with film of undeformed secondary muscovite developed interstitially to the larger primary constituents. A large potash felspar (lower right) crystal shows secondary muscovite plates orientated to its internal structure. The original grains of the rock have not yet become disarranged from their primary flow orientation. The film of muscovite crystals extends from five o'clock to nine o'clock on the photograph.

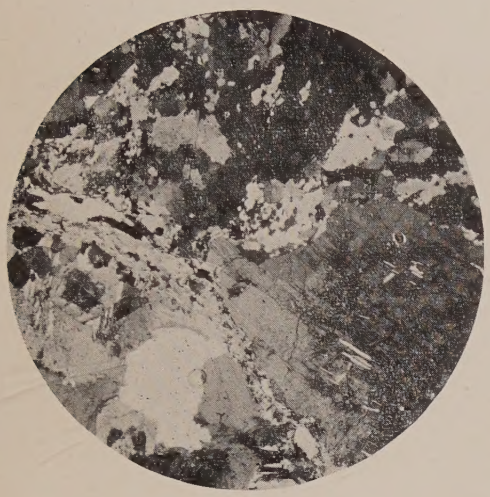
B.—Gneissose Granite. Mount Venus.

General cataclastic breakdown of the quartz ground-mass and development of secondary mica films in the foliation direction. Large bent and broken grains of the felspars and biotite are scattered with various orientations through the rock with development of a typical mortar structure.

C.—Mylonite, derived from the Granite. Just inside the contact, Mount Venus.

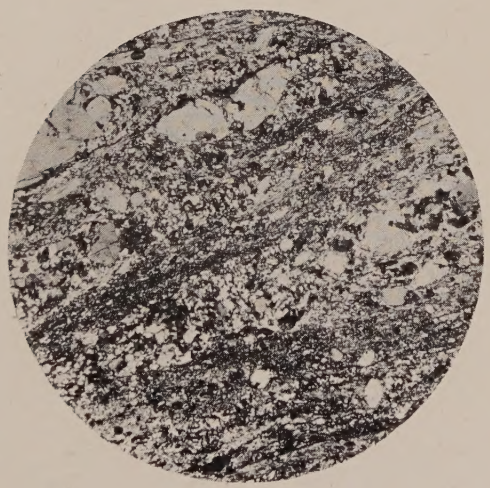
Wholesale cataclastic effects with reduction of the various constituents to a fine, and rather even-grained aggregate. Continuous sub-parallel films of white mica separate foliae made up of fragmented felspars and fine reconstituted mosaic quartz.

Photomicrographs by Mr. Geo. McLean, A.R.P.S.



A

B



C